Effect of Cross-Linked Resistant Starch on Wheat Tortilla Quality

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ABSTRACT

Resistant starch (RS) ingredients are an attractive option to increase dietary fiber in baked products. This study determined the effect of two forms of cross-linked and pregelatinized cross-linked RS, Fibersym-RW (Fsym) or FiberRite-RW (FRite), respectively, from wheat on dough and tortilla quality and acceptability. Refined wheat tortillas with 0% (control) to 15% RS (flour basis) were made using a standard baking process. Tortillas with 100% whole white wheat were also made. Physical and rheological properties of dough and tortillas, and sensory profile of tortillas were evaluated. Dough with whole wheat and 15% FRite were significantly harder and less extensible than the control dough; this was related to high water absorption of these doughs. Tortillas with whole wheat and 10–15% FRite were less puffed and denser than the control; however these levels of FRite significantly increased tortilla weight (by up to 6.2%). Dough and tortillas with Fsym were comparable to the control. Dietary fiber (g/100 g, db) increased from 2.8 ± 0.3 in control to 14.3 ± 0.5 and 13.6 ± 0.5 in 15% Fsym and 15% FRite tortillas, respectively. Tortillas with whole wheat were less acceptable than the control in appearance, flavor, and texture, while tortillas with 15% Fsym had higher overall acceptability than the control. Incorporation of 15% cross-linked wheat RS to increase tortilla dietary fiber is feasible without negatively affecting dough handling and tortilla quality.

Resistant starch (RS) is starch or its hydrolysis by-products that are not absorbed in the small intestine but are partially or completely fermented in the large intestine (Champ et al 2003; Higgins 2004). Short-chain fatty acids (SCFA), which are the main fermentation products of RS, may improve colonic muscular activity, regulate pathogen population and increase calcium absorption (Topping et al 2003). Other possible health benefits of RS include inhibition of tumor cells through butyrate production, enhancement of growth of beneficial bacteria in the colon (i.e., RS as prebiotic), and improved glycemic and insulinaemic responses (Sharma et al 2008).

RS can be found naturally in starch-rich products in the form of physically inaccessible starch, granular starch, or retrograded starch (Topping et al 2003). However, digestibility of naturally occurring RS changes with processing conditions, amylose to amylopectin ratio, and food particle size (Liljeberg et al 1996; Akeberg et al 1998; Kale et al 2002; Sharma et al 2008). On the other hand, commercially produced cross-linked RS (referred to as type 4 RS, or RS4) have an advantage of stability during processing. The RS4 starches also have very high DF content (up to 100% DF) (Woo and Seib 2009; Woo et al 2009), which allows for great flexibility in product formulation.

Adding RS ingredients into a baked product improves its nutritive profile by increasing dietary fiber content and providing associated health benefits. RS ingredients have an advantage over traditional high-fiber ingredients because they generally have low water-holding capacity, do not significantly affect dough handling properties, are bland in flavor, have small particle size, and may even improve the texture of the final product (Baixauli et al 2008a; Sharma et al 2008).

Flour tortillas have moved from being an ethnic (Hispanic) commodity to being part of a typical American diet. Versatility, convenience, and taste make tortillas highly acceptable to consumers. This popularity and acceptance make tortillas a good candidate for dietary fiber fortification and a powerful strategy to promote healthy eating. Unfortunately, many consumers are turned off by dull appearance and harsh flavors of whole grain or bran-fortified products. Wheat bran and other cereal fibers also tend to have high water-holding capacity, which negatively affects dough machinability and tortilla quality (Seetharaman et al 1994). Resistant starch may provide a convenient and functional source of dietary fiber for consumers who prefer the sensory properties of refined flour tortillas. However, so far, how the high dietary fiber RS4 starches affect tortilla processing and quality is unknown.

The objective of this study was to determine the effects of RS4 wheat starch on the physical and rheological properties of tortilla dough and tortillas, as well as consumer acceptability of the tortillas.

MATERIALS AND METHODS

Dough and Tortilla Preparation

Eight treatments were prepared with the same amount of ingredients, except for the amount of resistant starch (RS) substituted for refined wheat flour (untreated, bleached, enriched; ADM Milling Co., Overland Park, KS), which were 0 (control), 5, 10, and 15%. Two cross-linked resistant wheat starch ingredients were used: Fibersym RW (Fsym) and FiberRite RW (FRite) (MGP Ingredients, Atchison, KS). Composition data from the supplier indicated that Fsym and FRite have 85% and >75% total dietary fiber (TDF), respectively, as determined by AOAC Method 991.43. Both samples are considered RS4 ingredients (modified starch), but Fsym has low water absorption and is intended for baked goods, while FRite is a pregelatinized cross-linked starch that is able to absorb significant amounts of water while maintaining granule integrity and is meant for use in reduced fat formulations and as a thickener. Another treatment with no RS was prepared using whole white wheat flour (Farmer Direct Foods, Atchison, KS) instead of refined wheat flour.

Dough and tortillas were prepared as described by Alviola and Waniska (2008). Quantities of the other ingredients used (aside from 500 g of wheat flour/RS combination) were 30 g of shortening (Sysco, Houston, TX), 7.5 g of salt (Morton International, Chicago, IL), 3 g of sodium bicarbonate (Arm and Hammer, Princeton, NJ), 2.9 g of sodium aluminum sulfate (Budenheim USA, Plainview, NY), 2.5 g of sodium steroyl lactylate (Caravan Ingredients, Lenexa, KS), 2 g of sodium propionate (Niacet, Niagara Falls, NY), 2 g of potassium sorbate (B.C. Williams, Dallas, TX), 1.6 g of encapsulated fumaric acid (Balchem, New Hampton, NY), and 0.015 g of cysteine (Fleischmann's Yeast, Burr Ridge, IL). Water (distilled) addition was based on mixograph water absorption (–10%) (% flour basis) as control 52.0; whole wheat 56.0, 5% Fsym 54.7, 10% Fsym 60.0, 15% Fsym 64.7, 5% FRite 55.8, 10% FRite 62.2, 15% FRite 67.0.

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Subjective Evaluation of Dough Properties

Dough was subjectively evaluated using a 1–5 rating for smoothness, softness, extensibility, and force to extend (Alviola et al 2008). A score of 1 means the dough is very smooth, very soft, breaks immediately, and needs less force to extend. Conversely, a score of 5 means that the dough is very rough, very firm, excessively extensible, and needs much force to extend.

Hardness of dough was measured objectively with a texture analyzer (model TA-XT2i, Texture Technologies, Scarsdale, NY). A dough ball (≈2.1 cm thick, 5.2 cm diameter, 45 g) was placed on an aluminum platform and compressed at a speed of 10 mm/sec at 70% strain with an aluminum cylindrical probe (10 cm diameter). Peak force was determined as dough hardness (Barros 2009).

The extensibility test according to Smewing (1995), which uses the Kieffer dough and gluten extensibility rig attached to a texture analyzer, was followed with modifications. After resting the dough balls for 10 min in the proofing chamber (32°C, 70% RH), 20 g from one dough ball was taken and rolled into a cylindrical shape, placed into the grooved mold, rested for 40 min at room temperature, and evaluated. Dough extensibility and resistance to extension were determined.

Subjective Evaluation of Tortillas

Ten tortillas from each batch, prepared on two different days, were randomly selected and measured for weight, thickness, diameter, and opacity (Alviola et al 2008). Likewise, two tortillas from each batch were randomly selected and measured for color using a chromameter (model CR-300, Minolta Camera, Osaka, Japan). Values for L^* (brightness or whiteness), a^* (greenness to redness), and b^* (yellowness to blueness) were determined.

Tortilla samples were freeze-dried for total starch and dietary fiber analysis. Total starch was determined using Approved Method 76-13 (Megazyme Amyloglucosidase/α-amylase) (AACC International 2000). Total dietary fiber was determined using AOAC Method 985.29.

The tortillas were subjectively evaluated for shelf-stability using the rollability technique, 4, 8, 12, and 16 days after processing (Cepeda et al 2000). A tortilla was rolled around a 1-cm wooden dowel and rated from 1 (breaks immediately, cannot be rolled) to 5 (no cracks, very flexible). Tortillas were considered unacceptable when the rollability score was <3.

The two-dimensional extensibility test was done with a texture analyzer to get the texture profile of the tortillas (Alviola and Waniska 2008). Deformation modulus and force, distance, and work to rupture were determined after 0, 4, 8, 12, and 16 days of storage.

Sensory Evaluation

All eight treatments were evaluated for acceptability using a consumer panel consisting of 73 untrained panelists. Each sample was presented with an assigned random three-digit number code, and evaluated for texture, flavor, color, and overall acceptability using a 9-point hedonic scale (1 = dislike extremely, 9 = like extremely). Information about the panelists were also gathered (age, gender, ethnicity, and frequency of tortilla consumption).

Statistical Analyses

Analysis of variance (ANOVA) was performed in a completely randomized design using SPSS v11.0 for Windows for all dough and tortilla parameters. Mean difference between the refined flour (control) and each treatment was analyzed with a two-sided Dunnett's test ($\alpha = 0.05$).

RESULTS AND DISCUSSION

Dough Properties

Determining the effects of the added RS ingredient on dough properties is important to know if changes in processing conditions will be needed. A significant change in formulation may mean differences in dough machinability (i.e., ease of dividing, rounding, pressing, etc.).

Doughs with 5–15% Fsym and 5% FRite were as soft, extensible, and easy to press as the refined wheat dough (control) based on subjective evaluation (Table I). Dough with 10 and 15% FRite on the other hand was less soft and extensible, and also harder to press or handle than the control. Whole wheat dough was also less soft and extensible than its refined wheat counterpart. Objective evaluation with a texture analyzer confirmed that 15% FRite and whole wheat dough were harder and less extensible than the refined wheat dough (Table I). This was due to the type of fiber in whole wheat and FRite RS, which absorbed water and competed with the gluten in the dough system. Wheat bran is rich in water-soluble polysaccharides with high water-binding capacity, whereas FRite is primarily used as a viscosity modifier by manufacturers.

Whole wheat and 5, 10, 15% FRite treatments increased dough water absorption by 2% and 1, 3, 5%, respectively, relative to the control; Fsym increased water absorption by 1 and 3% at 10 and 15% substitution, respectively. Between the two RS ingredients, Fsym was easier to incorporate and process and behaved similar to control. Thus, the Fsym would more readily fit into existing tortilla processing protocol without the need for extensive adjustments. FRite worked liked traditional fiber ingredients and was comparable to whole wheat dough in that it increased water requirement and still had relatively harder dough after proofing.

This high water-holding capacity of fiber affects the dough properties and, consequently, the tortilla quality because it competes with gluten for water. Gluten has to absorb enough water to be fully developed and efficiently provide the needed structure of the final product.

TABLE I
Properties of Control and Resistant Starch-Fortified Dough Evaluated Subjectively and Objectively[a]

Parameter	Control Refined Wheat	Whole Wheat	Fibersym-RW 5%	Fibersym-RW 10%	Fibersym-RW 15%	FiberRite-RW 5%	FiberRite-RW 10%	FiberRite-RW 15%
Subjective[b]								
Softness	2.0	3.3*	1.8	2.0	1.8	2.0	2.8*	3.0*
Extensibility	3.8	1.8*	3.8	3.0	3.3	3.0	2.3*	1.5*
Force to extend	1.8	3.3	1.8	2.0	2.0	2.0	3.0	3.5*
Press rating	2.3	3.5	2.3	2.5	2.3	2.5	3.3	3.8*
Objective								
Hardness (N)	113	229*	142	122	112	124	130	221*
Resistance to extension (N)	0.40	0.62*	0.48	0.35	0.34	0.65*	0.50	0.57*
Extensibility (mm)	55.9	17.3*	26.8	39.3	41.6	39.7	32.3	20.6*

[a] Mean values from two trials. * Indicates significant difference from control ($P < 0.05$, Dunnett's test).
[b] Subjective dough evaluation scale. Softness (1 very soft, 5 firm); extensibility (1 not extensible, 5 very extensible); force to extend (1 less force, 5 much force); press rating (1 easy to press, 5 hard to press).

Tortilla Properties

Tortilla weight of whole wheat and Fsym tortillas were similar to control (Table II), even though the whole wheat and 15% Fsym doughs absorbed more water than control dough. The whole wheat tortilla likely lost more moisture in the oven due to its porous nature (larger particle size) relative to control. The Fsym dough likely lost more moisture in the oven than the control due to the fact that this particular RS4 has a poor ability to trap excess absorbed water due to very weak or limited hydrogen bonding sites with water. FRite tortillas on the other hand showed a significant ($P < 0.001$) and linear ($R^2 = 0.97$) (data not shown) trend of increasing weight with increased RS substitution (Table II). At 15% substitution, FRite tortillas weighed 6.2% more than control. Based on linear regression, every 1% increase in FRite substitution increased tortilla weight by 0.4%. Miller et al (2008) recently observed that substitution of wheat flour with pregelatinized cross-linked and hydroxypropylated wheat starches at 8.3% increased bread weight by 3.8%. They suggested this may be a promising strategy to increase bread yield. The FRite should be investigated further for potential to increase yield of tortillas (tortilla weight relative to dry ingredient input). However, its negative effect on dough handling would need to be overcome.

The 10 and 15% Fsym tortillas had significantly larger diameters, which is one of the key quality attributes of tortillas (Adams and Waniska 2002) compared with control tortillas (Table II); other treatments were similar to the control in diameter. This was likely due to the fact that the Fsym RS diluted the gluten network without significantly contributing to the dough intermolecular network during mixing (i.e., Fsym behaved like a relatively inert ingredient). The resulting dough was easy to spread with minimal shrink-back during pressing. Even though the whole wheat and 10 and 15% FRite doughs also significantly diluted gluten network, they produced doughs that were less extensible (Table I), thus resisted spreading, due to the hydrogen bond networks formed by water-soluble components (Neukom 1976).

Whole wheat tortillas were significantly thinner, less opaque, and had darker color than the control. The relatively large bran particles not only weakened the gluten matrix, making it less effective in maintaining the air bubbles from the leavening action, but also created a porous surface, allowing air bubbles to escape easily, resulting in thinner tortillas. Having less air bubbles also resulted in more translucency of the whole wheat tortillas because refraction of light from air bubbles contribute to opacity (Adams and Waniska 2002). The bran components in the whole wheat flour also gave a light brown color to the tortillas, thus significantly reducing its *L* value relative to the other samples (Table II). Tortillas with 10 and 15% FRite and whole wheat flour also had lower specific volume than the control. This means that they were

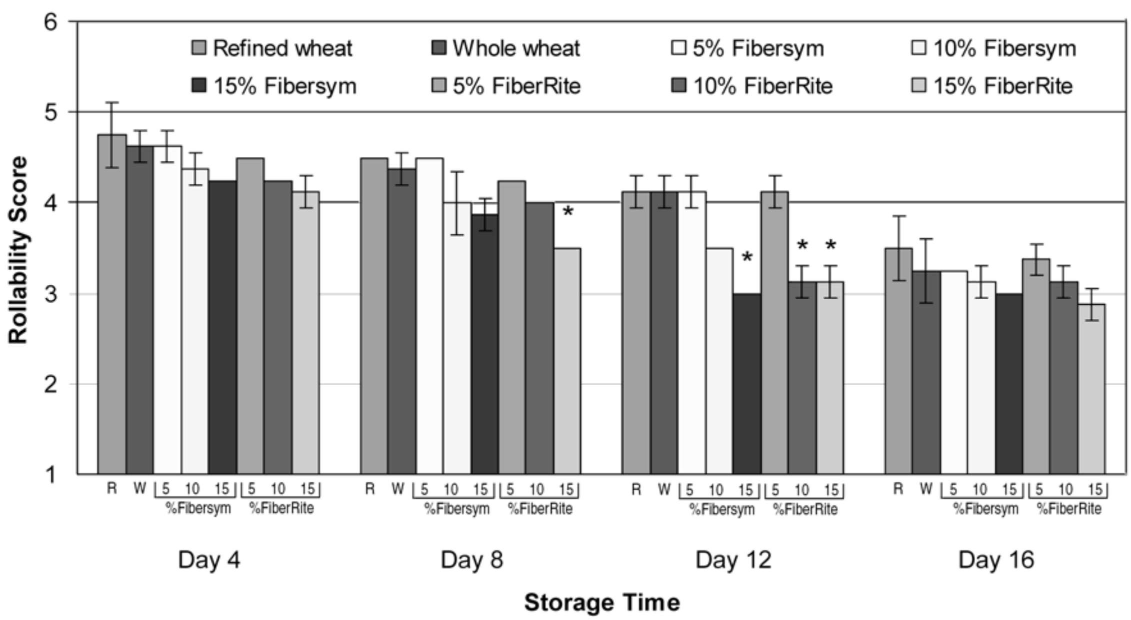

Fig. 1. Subjective rollability scores of control tortillas and tortillas fortified with resistant starch: 1 = breaks immediately, cannot be rolled; 5 = no cracks, very flexible. Error bars represent ± standard deviation. Bars with * significantly different from control within each day ($P < 0.05$; Dunnett's test).

TABLE II
Properties of Control and Tortillas Fortified with Resistant Starch[a]

Parameter	Control, Refined Wheat (RW)	Whole Wheat	Fibersym-RW 5%	Fibersym-RW 10%	Fibersym-RW 15%	FiberRite-RW 5%	FiberRite-RW 10%	FiberRite-RW 15%	% RSD
Weight (g)	40.5	39.5	40.8	40.2	39.3	41.3	41.8*	43.0*	1.4
Thickness (mm)	3.00	2.39*	3.00	2.82	2.81	2.95	2.79	2.84	2.2
Diameter (mm)	164	161	169	177*	176*	161	158	158	1.5
Opacity (%)	75	49*	85	88	90	74	69	77	4.7
Specific volume (cm^3/g)	1.57	1.24*	1.64	1.72	1.74	1.46	1.32*	1.29*	
*L**	81.5	64.4*	82.1	82.4	83.5	81.9	81.1	81.3	0.9
*a**	0.36	6.4*	0.37	0.14	0.13	0.38	0.61	0.60	36.6
*b**	19.0	21.9	18.7	17.8	16.2	18.3	18.3	17.7	3.8
Total starch (%, db)	68.0	54.5*	68.4	67.7	67.6	67.7	67.9	66.8	0.9
Total dietary fiber (%, db)	2.8	12.6*	nd	nd	14.3*	nd	nd	13.6	5.5

[a] Mean values from two trials. * Indicates significant difference from control ($P < 0.05$, Dunnett's test); nd, not determined.

less fluffy or puffed and more dense. Baixauli et al (2008b) observed a decrease in gas cells and height of muffins (i.e., denser muffins) with an increasing substitution of wheat flour with RS. Tortillas with Fsym, on the other hand, gave excellent tortilla quality (similar to control).

Total starch content of the control and RS-containing tortillas were similar with a range of 67–68% db (Table II). Tortillas from whole white wheat flour had significantly lower total starch (54%), as expected, because of the higher protein, fat, and nonstarch fiber content from the wheat pericarp and bran.

The substitution of 15% RS in refined tortilla flour increased dietary fiber content of the tortillas from 2.8 g/100 g db to 14.3 and 13.6 g/100 g db for Fsym and FRite, respectively (Table II). Whole wheat tortillas had 12.6 g/100 g db of dietary fiber. These values translate to 0.8 g of dietary fiber/serving (40 g of tortilla) for refined flour tortilla. Tortillas with whole wheat, 15% Fsym, and 15% FRite had 3.5, 3.9, and 3.6 g of fiber/serving, respectively. Thus, both 15% RS4 substituted tortillas qualified as "good sources" of fiber based on FDA allowed nutrient content claim.

Subjective rollability scores of tortillas on day 4 of storage were similar between the control and the treatments (Fig. 1). By the day 8 of storage, 15% FRite tortillas were significantly less flexible than the control; while at day 12, both 10 and 15% RS4 substituted tortillas were less flexible than the control. However, based on the rollability scores, all tortillas were still acceptable (scores ≥3). After 16 days, the treated tortillas were not different from the control; all still had acceptable rollability scores (Alviola et al 2008).

Objective texture evaluation with a texture analyzer showed an increase in deformation modulus with storage time (Table III), which means more force/mm was needed to deform tortillas as they staled, primarily due to starch retrogradation (Alviola and Waniska 2008). This was accompanied by a decrease in both extensibility (rupture distance) and work required to rupture the tortilla (Table III). The fresh (day 0) Fsym-substituted samples had significantly lower deformation modulus (0.64–0.66 N/mm) compared with the control (0.76 N/mm), while whole wheat tortillas had higher values (0.89 N/mm) than the control. This indicates that at day 0, tortillas with Fsym were softer and more tender than the control tortilla, probably due to the fact that this cross-linkage did not significantly participate in intermolecular bonding and mainly acted as a diluent and partial inhibitor of starch amylase network formation during baking. Whole wheat tortilla, on the other hand, was less tender than control, probably due to effect of water-soluble bran polysaccharides that participated in cross-linkages with starch and proteins (Neukom 1976). By day 16, all samples had similar textural profiles as measured by the texture analyzer.

Sensory Evaluation

One-day-old tortillas were evaluated for consumer acceptability of appearance, flavor, and texture using a 9-point hedonic scale. The untrained panel was composed of 55% females and 45% males, with 67% in an age range of 18–40. The two major ethnic groups represented were Caucasians (40%) and Hispanics (23%). When asked frequency of tortilla consumption, 40% said at least once a week and 30% said once every two weeks.

Among the treatments, only the whole white wheat tortillas were significantly less acceptable than the control in overall acceptability, appearance, flavor, and texture (Table IV). This agrees with the results of Friend et al (1992), wherein the increase in substitution of refined wheat with whole wheat flour gave a corresponding decrease in consumer acceptability of tortillas. This also underscores a broader consumer dislike for whole grain products, thus necessitating alternative strategies to deliver dietary fiber to consumers.

TABLE III
Texture Changes of Tortillas Fortified with Resistant Starch[a]

	Deformation Modulus (N/mm)		Rupture Distance (mm)		Work (N·mm)	
	Day 0	Day 16	Day 0	Day 16	Day 0	Day 16
Control, refined wheat (RW)	0.76	1.19	19.6	11.4	75.3	34.9
Whole wheat	0.89*	1.36	14.9	10.0	55.7	29.5
Fibersym-RW						
5%	0.66*	0.95	20.1	11.7	67.2	31.9
10%	0.64*	0.94	17.2	10.7	46.9	21.6
15%	0.68*	0.85	17.3	10.6	50.7	20.3
FiberRite-RW						
5%	0.70	1.16	19.2	10.7	67.8	28.4
10%	0.77	1.33	18.2	10.1	68.7	26.8
15%	0.81	1.09	15.8	9.8	57.6	20.1

[a] Mean values from two trials. * Indicates significant difference from control ($P < 0.05$, Dunnett's test).

TABLE IV
Sensory Evaluation Scores of Tortillas Fortified with Resistant Starch[a,b]

	Overall Acceptability	Appearance	Flavor	Texture
Control, refined wheat (RW)	6.6	7.2	6.7	6.7
Whole wheat	5.5*	5.9*	5.3*	5.8*
Fibersym-RW				
5%	6.3	7.1	6.5	7.1
10%	7.0	7.2	6.8	7.8*
15%	7.5*	7.6	7.3	8.2*
FiberRite-RW				
5%	6.8	7.2	6.6	6.5
10%	6.9	7.2	7.2	7.0
15%	6.5	6.9	6.7	6.4
% RSD [c]	16.6	16.4	18.8	17.4

[a] Mean values from two trials. * Indicates significant difference from control ($P < 0.05$, Dunnett's test).
[b] Hedonic scale (1 dislike extremely, 5 neither like nor dislike, 9, like extremely).
[c] Relative standard deviation.

Tortillas with Fsym generally had higher scores for texture than the control, which confirms the objective textural data described above (these tortillas were generally more tender). Baixauli et al (2008a) also observed higher texture acceptability scores in muffins with 10% RS. Interestingly, tortilla with 15% Fsym had significantly higher overall acceptability scores than the control tortilla, suggesting this RS may be a valuable functional dietary ingredient for tortillas. The FRite tortillas were judged similar to control, which also agrees with objective measurements described above. However, this particular RS had a negative effect on dough machinability and quality (Table I) due to high water absorption capacity.

CONCLUSIONS

It is technically feasible to substitute part of the wheat flour in tortillas with low water-absorbing cross-linked RS4 wheat starch ingredients without significantly affecting dough machinability or product quality and acceptability. The Fsym RS manufactured from wheat was generally bland and did not interfere with dough handling, thus ≤15% was successfully incorporated in tortillas, resulting in high dietary fiber content of the final product that met FDA requirement for "good source of fiber" claim. This opens opportunities for manufacturers to create and promote healthier versions of tortillas to market segments that prefer refined flour tortilla products. However, because the RS ingredients are more expensive than wheat flour, such RS-substituted tortillas are likely to sell at a premium, which is not unusual for products that offer potential health profiles.

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